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Abstract.

Because of the growing epidemic of gluten intolerance, there is growing interest in gluten-free foods. Beyond just being gluten-free, such foods can have other positive nutritional benefits to human health. Extrusion processing is commonly used to produce a wide variety of human food products. Gluten-free grains can be a processing challenge, however, due to lack of proper binding, which can lead to poor quality food products. This research explores how extrusion parameters impacted the quality of amaranth- and quinoa-based extrudates. The specific objectives of this project included extruding each of the grains, then measuring extrudate properties, such as color, unit density, expansion ratio, and durability. Both the quinoa and amaranth were extruded as raw grain, as well as ground to 2mm and 1mm particle sizes. Other experimental conditions included moisture contents of 20% and 40% (d.b.), and extruder screw speeds of 50 rpm and 100 rpm. All treatments were successfully extruded, and all extrudates had high quality attributes, making this the first time either quinoa or amaranth was extruded without any binding ingredients.

Keywords. *Extrusion, grains, amaranth, quinoa, gluten-free.*

INTRODUCTION

Extrusion is a process that produces a variety of foods from fundamental ingredients. This process utilizes an extruder to produce foods such as ready-to-eat cereal, pasta, candy, croutons, flour, and pet food. There are several types of extruders for food production, including single-screw and twin-screw. However, they all usually serve the same purpose: to produce various foods from certain starting materials and under specific extrusion conditions. Extrusion is most often used to cook, texturize, expand, and shape the desired food. During this process, raw ingredients are inserted into the extruder, customarily through a feed bin. The main screw inside the extruder is operated by the power supply and mixes the substance while it is being heated. As this happens the product is moving toward the die, where it exits the machine. Upon leaving the machine, the product usually increases in size due to the release of steam.

Numerous studies have shown that extrusion has a definite positive nutritional effect on food. According to a study by Singh et al. (2007), these advantageous results include the destruction of anti-nutritional factors, increased soluble dietary fiber, reduction of lipid oxidation, and the gelatinization of starch. There are, however, very specific extrusion conditions necessary to produce a product that possesses these properties. These conditions vary depending on what is being extruded, but there appear to be some common necessary elements among the different foods. We know, for example that if the extrusion temperature is too high, burning and jamming of the machine results. On the other hand, if temperature is too low, the necessary pellets may not form. Moisture content also plays a very significant role in the process. If the moisture content is too high the extruder will become jammed. However, if there is not enough moisture in the mix, the product will not stay bound. The studies that Singh conducted showed that the best overarching extrusion conditions for high nutritional quality were high moisture content, low residence time, and low temperatures.

While the market for extruded cereals and snacks is quite large, it seems to be shrinking everyday, as more people begin gluten free diets. A gluten–free lifestyle is an increasingly popular dietary option that urges people to give up all products containing gluten in their diets. A large portion of society is choosing this dietary option for a variety of health reasons such as the progressively common celiac disease. While gluten is also one of the most common food intolerances, many people also choose to participate in gluten free diets for non-medical reasons. For all of these reasons, the gluten free market is rapidly growing. If we were able to utilize the technology of extrusion to produce gluten-free snacks, this would greatly expand the market for extruded products. The production of gluten free snacks by way of extrusion would be a huge step forward for the snack producing industry.

The grains that are commonly used to take advantage of the nutritious benefits of extrusion are corn and rice. There is, however, the possibility of producing extremely healthy foods from less common grains such as quinoa, and amaranth. Both of these grains are gluten-free. The growing gluten–free market provides a huge potential opportunity for extruded gluten-free products.

Quinoa is one of the grains that falls into the gluten free category. The largest producers of this grain are Bolivia and Peru with 88% of the world's quinoa. The next largest producer is the United States with only a shear fraction of its production, 6%. This is an ideal seed to grow because it is drought and frost resistant, grows in poor soil, and grows at high altitudes. Like chia, quinoa is ideal for use in the extrusion of snack foods because of its health benefits. According to a study by Vilche et al. (2003), these seeds contain 10% to 18% protein, 4.5% to 8.75% crude fat, 54.1% to 64.2% carbohydrates, 2.4% to 3.64% crude fiber, and a first limiting amino acid of lysine, which is readily available in these seeds. This alone shows quinoa to be nutritionally superior to wheat. Another study, by Ahamed et al. (1998), had very similar results to these for the chemical composition of quinoa. The results of this study are shown in Table 6. The high protein content of quinoa makes it a great alternative to flour for gluten free goods. Also, the fact that it is low in fat makes quinoa a promising grain to end up with a cohesive extrudate. A study done by Dogan and Karwe (2003) discusses the properties of this grain after extrusion. It was found that the protein is rich in lysine, methionine, and cysteine. This extrudate also has more than double the protein of corn and rice. For all of these reasons, quinoa is an ideal grain to extrude for the purpose of producing gluten free snacks.

Amaranth is yet another gluten free grain. It is most common in Peru, Bolivia, and Mexico. Its yields change significantly depending on the growing season, location, and soil moisture. Similar to the other two grains, Amaranth is an ideal grain to use in the extrusion of gluten free snack foods. It has definite health benefits as well. A study by Abalone et al. (2004) shows that these seeds have 16% to 18% protein, and high lysine and tryptophan content. A study done by Ahamed et al. (1998) showed amaranth to have 13-18% protein, 6-8% fat, 63% carbohydrates, and 4-14% crude fiber. Similar to quinoa, amaranth has high protein content, making it ideal to use in gluten free goods. The low fat content of amaranth makes it an ideal grain to extrude without jamming the machine. Another study, conducted by Ilo et al. (1999), discussed the extrusion of amaranth. The study found that extruding this grain helped to increase the availability of protein and nutrients. Due to the positive nutritional qualities of amaranth and the fact that it is gluten free, it is an ideal grain to extrude into gluten free snack foods.

Both of the grains discussed have nutritional qualities of value to the human body. Several studies have shown that extruding these grains has further increased their nutritional value. The purpose of this project is to utilize the grains quinoa and amaranth to produce gluten free snacks.

MATERIALS AND METHODS

Raw Ingredients

White quinoa seeds were obtained from Roland. Amaranth was obtained from Angelina's Gourmet. Two kilograms of each of the raw ingredients were ground using a Wiley laboratory mill (model 4, Thomas Scientific, Swedesboro, NJ) to an average particle size of 2 mm, two kilograms were ground using a 1 mm screen, and two kilograms were left raw. Moisture content of each was determined using a drying oven at 135°C for two hours. Enough water was added to one kilogram of each sample to achieve 20% db moisture and to the other kilogram to reach 40% db moisture. The products were divided into the following categories: raw grain at 20% and 40% moisture content, 1 mm particle size at 20% and 40% moisture content, and 2 mm particle size at 20% and 40% moisture content.

Extrusion Processing

The extrusion of each of the blends was carried out using a single-screw extruder (model PL 2000 Plasti-Corder, Brabender South Hackensack, NJ) with a screw compression ratio of 1:1, a screw length-to-diameter ratio of 20:1, and a barrel length of 317.5 mm (Figure 1). The die had a diameter of 3.0 mm. Each blend was extruded at screw speeds of

50 rpm and 100 rpm. The raw blends were manually scooped into the barrel of the extruder and forced through with a wooden rod to ensure no jamming would take place. Temperatures were monitored at the feed, transition, and die zones.

Raw Ingredient Properties

After the ingredients were mixed to their necessary moisture contents, the blends were analyzed in terms of color. To determine the color of the mixtures, a spectrometer (LabScan XE, HunterLab, Reston, VA) was used. The L value measured the lightness/darkness, the a* value quantified the redness/greenness, and the b* value signified the yellowness/blueness. The moisture content of the raw ingredient mixes were also tested for moisture content after extrusion to ensure the values matched the expected moisture contents.

Extrudate Properties

After extrusion, the products were dried in a laboratory oven at 50° C for 24 hours. The extrudates were then analyzed for color, unit density (kg/cm^3), expansion ratio, and pellet durability index (%). The extrudate color was measured using the same process as the raw ingredient color was measured. A spectrometer (LabScan XE, HunterLab, Reston, VA) was used to determine the L value (measuring lightness/darkness), the a* value (measuring redness/greenness), and the b* value (measuring yellowness/blueness). To measure unit density, each extrudate was cut to sections of length 20 mm. They were then weighed on a balance and measured with a caliper to conclude their diameters. The unit density was determined by dividing the mass (kg) by the volume (cm^3) because of the extrudates' cylindrical shape. To calculate the expansion ratio, the actual diameter of the extrudates (mm) was divided by the diameter of the die (3 mm). To measure pellet durability index, 100 g of each extrudate was tumbled in a pellet durability tester (model PDT-110, Seedburo Equipment, Chicago, IL) for 10 min. Then, products were sieved for 15 sec, and again weighed on an electronic balance. The final weight was divided by the initial weight (100 g) and multiplied by 100, resulting in a percentage. The results of these analyses are shown in Table 3 and Table 5 for quinoa and amaranth, respectively. Figure 2 and Figure 4 show the blends before and after extrusion for comparison.

Experimental Design

The experimental design was based on a 3x2x2 matrix with varying dependent variables of particle size, moisture content, and screw speed, respectively (as shown in Table 1). Particle size was divided into 3 groups of raw grain, 2mm average particle size, and 1mm average particle size. Moisture content was split into 2 categories of 20% db and 40% db. All 6 blends were extruded at screw speeds 50 rpm and 100 rpm, resulting in 12 different treatment options.

Data Analysis

For each extrudate, all physical properties were measured 3 separate times except durability where one measurement was taken. All measurements were used to calculate the average and standard deviation of each property. Measured properties included both measurements from raw grain (moisture content, and L*, a*, and b* color) and the extrudates (L*, a*, b*, unit density, expansion ratio, and pellet durability).

RESULTS AND DISCUSSION

Raw Ingredient Properties

Moisture Content: Not only is moisture content of the extrudates important, but moisture content of the raw grains is as well. This is a large indicator as to how easily the blend will extrude. If moisture content is too low, the final product will not stay bound. However, if the moisture content of the blend is too high, the blend will jam the extruder and not produce a product. Table 3 and Table 5 show, in column 3, the actual moisture content of blends for quinoa and amaranth, respectively. The average moisture content of the 20% db quinoa was 23.67% db, and the average moisture content for the 40% db quinoa was 41.11% db. For amaranth, the average moisture content of the 20% db grain was 24.29% db, and the average moisture content for the 40% grain was 42.17% db. The variance was low for the moisture content of both grains and the mixtures were utilized for the extrusion.

Color: Color was measured for each blend before extrusion and the quinoa results are also seen in Table 3. For quinoa, the L* value decreased for each grain size as moisture content increased from 20 to 40%. There was no correlation between moisture content and particle size and either a* or b*. The amaranth data is shown in Table 5. Neither moisture content or particle size have an impact on the L* value. However, a* decreases as grain size decreases. B* decreases as both moisture content and particle size decrease.

Extrudate Properties

Table 3 displays the quinoa extrudate properties. It shows what effects moisture content, grain particle size, and extruder screw speed had on color (L*, a*, b*), unit density, expansion ratio, and pellet durability index. The values included in this table are the average of 3 trials and the standard deviation for each extrudate property. Table 5 shows the same extrudate properties for amaranth. It also provides the effects of the same control variables stated above on the properties of color (L*, a*, b*), unit density, expansion ratio, and pellet durability index.

Color: Extrudate color is very important when it comes to customer approval, especially when dealing with human foods. If the extrudate doesn’t visually appeal to the consumers, it is a problem. The three categories by which color is measured are L*, a*, and b*. According to the quinoa data in Table 3, Treatment 4 had the highest L* value of 69.14 and Treatment 12 had the lowest with a value of 56.4. As the screw speed increased, L* decreased. The lowest a* value of 3.22 came from Treatment 9. The highest value of 6.55 came from Treatment 3, which was significantly higher than all of the other treatments. Data analysis showed that as the moisture content increased, the a* value of the extrudates increased, but as the particle size decreased, the a* values decreased. The lowest b* value came from Treatment 9, and was measured to be 18.44, which was considerably lower than the other values. The highest b* value of 27.81 was measured from Treatment 4. Treatments 1, 2, 3, and 4, which were all blends made with raw grain, had higher b* values than the rest of the treatments. As the particle size decreased, b* values decreased. As the screw speed increased, the b* value increased as well. According to the amaranth data in Table 5, the lowest L* value, from Treatment 8, of 49.75, was significantly lower than any other L* value. The highest L* value was 67.02, from treatment 11. As the screw speed increased, the L* value increased as well. The lowest measured a* value was from Treatment 10 and was measured as 6.19. Other low a* values were from Treatments 8, 11, and 12. The highest value was 9.64, from Treatment 3. As the particle size decreased, there was a decrease in a*. Amaranth appeared to have higher a* values than quinoa did, meaning it was more red than green on the color scale. Significantly lower than the rest, Treatment’ 11’s b* value was 19.23. The highest value came from Treatment 2 at 29.09. Other treatments with high b* values were Treatments 4 and 6. As the grain size decreased, b* decreased. However, as the screw speed increased, so did b*. The more moisture a grain contains, the darker it tends to be. This means that the L* value would be lower. Since amaranth had the lowest L* value, it is likely less water evaporated from the amaranth blends than it did from the quinoa blends.

According to a study by Taverna et al. (2012), in an extrusion of quinoa flour and industrial sour cassava blends, after extrusion, the blends' L values varied from 53.05 to 74.69, which are similar to the values found in Table 3. The same study also shows that the L value decreased after extrusion, which is consistent with Table 3 as well. The study with the blends of quinoa and industrial sour cassava had a* values ranging from 4.64 to 6.43 (Taverna, 2012). These a* values are also similar to those in Table 3. The amaranth and sour cassava blends had b values from 10.88 to 20.86 (Taverna, 2012). These values for b* are significantly lower than those found in Table 3.

61.91 59.6

Unit Density: Due to the need to control nutrients in extruded foods, unit density is an important property to measure. Table 3 shows that Treatment 3 had the lowest unit density of quinoa, with a value of 1.1 g/cm^3. Treatments 1, 2, 5, 8, and 10 also had very low unit density values. The highest value of mass per unit density came from Treatment 4, which was significantly higher than any of the other treatments. Treatment 4 had a unit density of 1.51 g/cm^3. There was no correlation between unit density and moisture content, particle size, or screw speed. According to Table 5, the amaranth blend with the lowest unit density was Treatment 2, with a value of 0.9 g/cm^3. This is considerably lower than any other treatments. Treatment 3 had the highest unit density with a value of 1.43 g/cm^3. Treatments 3 and 4 had substantially larger unit density values than the rest of the treatments. As the moisture content in the amaranth blends increased, the extrudates' unit density increased. The two grains likely had similar unit densities because they were both tested at the same moisture content levels. Our results show that amaranth had significantly lower values for unit density than did quinoa. According to Table 6, quinoa was much higher in the percentages of carbohydrates than amaranth, so this may explain the higher unit density.

Expansion Ratio: The expansion ratio is the amount that the product puffs upon exiting the extruder and is a very important property when it comes to extrusion of human snack foods. According to Table 3, Treatments 4 and 11 were the quinoa blends with the lowest expansion ratios of 0.92 and 0.99, respectively. These were the only two treatments with expansion ratios below 1, meaning they shrunk in size upon exiting the extruder. The largest value of expansion ratio came from Treatments 5 and 10, both with values of 1.13. As moisture content of the blends increased, there was a decrease in the expansion ratio of the extrudates. According to Table 5, the amaranth blend with the lowest unit density was Treatment 2, with a value of 0.9. This was the only treatment with an expansion ratio less than 1. Treatment 9 had the highest value of 1.34, which was considerably larger than the other treatments. As the blends' moisture content increased, the extrudates' expansion ratio decreased. Both grains had similar expansion ratios. This may be due to the fact that they were both extruded at the same moisture contents, which usually has the biggest affect on expansion. However, protein content may have large effects on expansion ratio as well. This is also consistent with the results in Tables 3, 5, and 6. According to Table 6, the protein content in both quinoa and amaranth were between 12 and 19%. Tables 3 and 5 show that the expansion ratios in both grains were very similar. Quinoa had an average expansion ratio of 1.06, and amaranth of 1.1. The blends' similar moisture and protein contents likely led to the comparable expansion ratios.

Pellet Durability Index: Pellet durability index (PDI) measures the breakage the extrudate is able to endure, and has great importance in the storage of foods. The higher the percentage, the stronger and less likely the product is to break. According to Table 3, the quinoa blend with the lowest pellet durability index was Treatment 2, with a PDI value of 68.6%, which was significantly lower than the other treatments. Treatments 1 and 9 were similar in PDI values at 81.9 and 88.2%, respectively. The highest pellet durability index value came from Treatment 11, with 99.6%. Other high PDI values were from Treatments 5, 7, and 10 with values of 97.1, 98.4, and 98.5%, respectively. According to Table 5, the amaranth blends with the lowest pellet durability index were Treatments 1 and 9 with values of 80 and 80.2%, respectively. The treatments with the highest PDIs were Treatments 7 and 8 at 98.3 and 98.4%, respectively. Protein content usually has an effect on durability of extrudates. However, it is likely that a quinoa treatment had the lowest PDI because according to Table 6, it may contain more fat than amaranth. The more fat the grain contains, the less cohesive the extrudates tend to be.

CONCLUSONS

It is possible to produce extruded products from the pure grains of quinoa and amaranth, mixed with only water. These grains can both be extruded at particle sizes of raw grain, 2mm, and 1mm, and at moisture contents of 20% db and 40% db. All extrusion was carried out on a single screw extruder with screw speeds of 50 rpm and 100 rpm. Temperature was not regulated throughout the process, and does vary as shown in Table 2 and Table 4 for quinoa and amaranth, respectively. Figure 3 and Figure 5 plot the temperature against each measured property to determine what relationships the changing temperatures have with the results for quinoa and amaranth, respectively. Physical properties of both raw blends and extrudates are shown in Table 3 and Table 5 for quinoa and amaranth, respectively. Analysis showed that as the moisture content increased, the a* value of the extrudates increased, and there was a decrease in the extrudates' expansion ratio. As the quinoa particle size decreased, the a* and b* values decreased in the extrudates. As the screw speed of the extruder increased, the extrudates' L* value decreased, and the b* value increased. For amaranth, data analysis showed that as the moisture content increased, the expansion ratio of the extrudates decreased and their unit density and durability increased. As the particle size decreased, there was a decrease in the extrudates' a* and b* values. As the extruder's screw speed increased, the L* and b* values of the extrudates increased.

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Table 1: Experimental protocol including treatment numbers and dependent variables.

Treatment	Particle Size	Moisture Content (% db)	Screw Speed (rpm)
1	Raw	20	50
2		20	100
3		40	50
4		40	100
5	2 mm	20	50
6		20	100
7		40	50
8		40	100
9	1 mm	20	50
10		20	100
11		40	50
12		40	100

Table 2: Temperatures measured at the die, transition, and feed zones for the extrusion of quinoa.

Treatment	Temperature (°C) Die	Transition	Feed
1	54	50	29
2	45	50	36
3	54	42	30
4	55	69	33
5	60	59	32
6	54	64	36
7	59	58	34
8	58	72	42
9	38	59	31
10	61	76	46
11	28	34	23
12	61	71	44

Table 3: Mean properties of quinoa extrudates (standard deviation in parentheses).

Treatment	Trial	**Raw Properties** Moisture Content (db, %)	Color L*	Color a*	Color b*	**Extrudate Properties** Color L*	Color a*	Color b*	Unit Density (g/cm^3)	Expansion Ratio	Pellet Durability Index (%)
1	Average	21.87	76.16	3.79	25.99	65.31	4.83	26.14	1.16	1.12	81.9
	Standard Deviation	(0.32)	(0.14)	(0.02)	(0.18)	(0.03)	(0.01)	(0.01)	(0.05)	(0.02)	-
2	Average	21.87	76.16	3.79	25.99	64.81	4.55	26.94	1.14	1.09	68.6
	Standard Deviation	(0.32)	(0.14)	(0.02)	(0.18)	(1.14)	(0.15)	(0.38)	(0.04)	(0.02)	-
3	Average	39.84	75.41	3.6	24.28	57.78	6.55	24.23	1.1	1.06	92
	Standard Deviation	(0.79)	(0.02)	(0.02)	(0.01)	(0.12)	(0.02)	(0.01)	(0.03)	(0.01)	-
4	Average	39.84	75.41	3.6	24.28	69.14	5.35	27.81	1.51	0.92	95.8
	Standard Deviation	(0.79)	(0.02)	(0.02)	(0.01)	(0.23)	(0.21)	(0.26)	(0.45)	(0.12)	-
5	Average	25.42	84.65	2.29	19.47	61.59	4.1	21.8	1.15	1.13	97.1
	Standard Deviation	(0.33)	(0.02)	(0.01)	(0.01)	(0.03)	(0.03)	(0.02)	(0.09)	(0.01)	-
6	Average	25.42	84.65	2.29	19.47	58.07	3.7	20.98	1.21	1.09	96.4
	Standard Deviation	(0.33)	(0.02)	(0.01)	(0.01)	(0.14)	(0.01)	(0.06)	(0.02)	(0.01)	-
7	Average	44.45	83.36	2.38	18.57	67.53	4.8	20.3	1.25	1.03	98.4
	Standard Deviation	(1.30)	(0.04)	(0.01)	(0.01)	(0.24)	(0.02)	(0.04)	(0.04)	(0.01)	-
8	Average	44.45	83.36	2.38	18.57	56.85	4.71	21.53	1.17	1.07	96
	Standard Deviation	(1.30)	(0.04)	(0.01)	(0.01)	(0.09)	(0.02)	(0.03)	(0.05)	(0.04)	-
9	Average	23.72	85.62	1.85	18.6	60.01	3.22	18.44	1.25	1.1	88.2
	Standard Deviation	(0.69)	(0.07)	(0.05)	(0.16)	(0.32)	(0.03)	(0.01)	(0.07)	(0.03)	-
10	Average	23.72	85.62	1.85	18.6	58.09	3.86	21	1.17	1.13	98.5
	Standard Deviation	(0.69)	(0.07)	(0.05)	(0.16)	(0.67)	(0.03)	(0.17)	(0.08)	(0.05)	-
11	Average	39.04	81.71	2.4	19.91	67.35	4.17	19.76	1.21	0.99	99.6
	Standard Deviation	(0.47)	(0.02)	(0.01)	(0.01)	(0.64)	(0.03)	(0.17)	(0.10)	(0.02)	-
12	Average	39.04	81.71	2.4	19.91	56.4	5.22	24.1	1.29	1.04	96
	Standard Deviation	(0.47)	(0.02)	(0.01)	(0.01)	(0.46)	(0.04)	(0.32)	(0.04)	(0.01)	-

Table 4: Temperatures measured at the die, transition, and feed zones for the extrusion of amaranth.

Treatment	Temperature (°C)		
	Die	Transition	Feed
1	30	39	25
2	25	25	25
3	43	52	27
4	38	51	27
5	52	53	29
6	50	53	29
7	56	53	30
8	54	54	30
9	57	47	31
10	57	48	30
11	57	45	30
12	56	47	30

Table 5: Mean properties of amaranth extrudates (standard deviation in parentheses).

		Raw Properties				**Extrudate Properties**					
		Moisture Content		Color			Color		Unit Density	Expansion	Pellet Durability
Treatment	Trial	(db, %)	L*	a*	b*	L*	a*	b*	(g/cm^3)	Ratio	Index (%)
1	Average	24.5	63.33	7.24	29.09	59.99	9.01	27.25	1.11	1.07	80
	Standard Deviation	(0.29)	(0.06)	(0.01)	(0.01)	(0.01)	(0.03)	(0.01)	(0.06)	(0.03)	-
2	Average	24.5	63.33	7.24	29.09	66.33	7.24	29.09	0.9	1.18	82.5
	Standard Deviation	(0.29)	(0.06)	(0.01)	(0.01)	(0.06)	(0.01)	(0.01)	(0.08)	(0.03)	-
3	Average	41.61	63.52	8.4	28.62	53.18	9.64	26.13	1.43	1.04	95.9
	Standard Deviation	(1.63)	(0.03)	(0.01)	(0.01)	(0.02)	(0.01)	(0.03)	(0.36)	(0.01)	-
4	Average	41.61	63.52	8.4	28.62	63.52	8.4	28.62	1.25	1.07	93.6
	Standard Deviation	(1.63)	(0.03)	(0.01)	(0.01)	(0.03)	(0.01)	(0.01)	(0.05)	(0.02)	-
5	Average	24.19	25.3	7.08	28.43	56.41	8.42	25.38	1.08	1.16	95.3
	Standard Deviation	(0.23)	(0.06)	(0.04)	(0.06)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	-
6	Average	24.19	25.3	7.08	28.43	65.2	7.08	28.43	1.11	1.15	94.4
	Standard Deviation	(0.23)	(0.06)	(0.04)	(0.06)	(0.06)	(0.04)	(0.06)	(0.04)	(0.02)	-
7	Average	43.19	65.68	6.78	26.4	49.75	8.53	23.33	1.14	1.03	98.3
	Standard Deviation	(0.68)	(0.03)	(0.01)	(0.03)	(0.03)	(0.01)	(0.06)	(0.02)	(0.01)	-
8	Average	43.19	65.68	6.78	26.4	65.68	6.78	26.4	1.16	1.03	98.4
	Standard Deviation	(0.68)	(0.03)	(0.01)	(0.03)	(0.03)	(0.01)	(0.03)	(0.07)	(0.03)	-
9	Average	24.17	67.02	6.19	26.11	52.34	7.02	21.81	1.02	1.34	81.7
	Standard Deviation	(0.04)	(0.04)	(0.02)	(0.09)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	-
10	Average	24.17	67.02	6.19	26.11	67.02	6.19	26.11	1.01	1.14	80.2
	Standard Deviation	(0.04)	(0.04)	(0.02)	(0.09)	(0.04)	(0.02)	(0.09)	(0.03)	(0.01)	-
11	Average	41.71	62.59	6.42	24.97	53.3	6.27	19.23	1.13	1.05	95.3
	Standard Deviation	(0.84)	(0.05)	(0.01)	(0.03)	(0.03)	(0.03)	(0.01)	(0.03)	(0.01)	-
12	Average	41.71	62.59	6.42	24.97	62.59	6.42	24.97	1.18	1.05	96.2
	Standard Deviation	(0.84)	(0.05)	(0.01)	(0.03)	(0.05)	(0.01)	(0.03)	(0.05)	(0.02)	-

Table 6: Typical chemical properties of quinoa and amaranth seeds.

Grain	Moisture	Ash	Protein	Fat	Carbohydrate	Crude Fiber
Quinoa	10-13%	3%	12-19%	5-10%	61-74%	2-3%
Amaranth	6-9%	3-4%	13-18%	6-8%	63%	4-14%

Figure 1: Brabender single-screw extruder used to extrude blends. Conditions included a 3 mm die and a screw compression ratio of 1:1.

Figure 2: Raw quinoa (above) and extrudates (below) for treatments 2, 6, and 10, respectively.

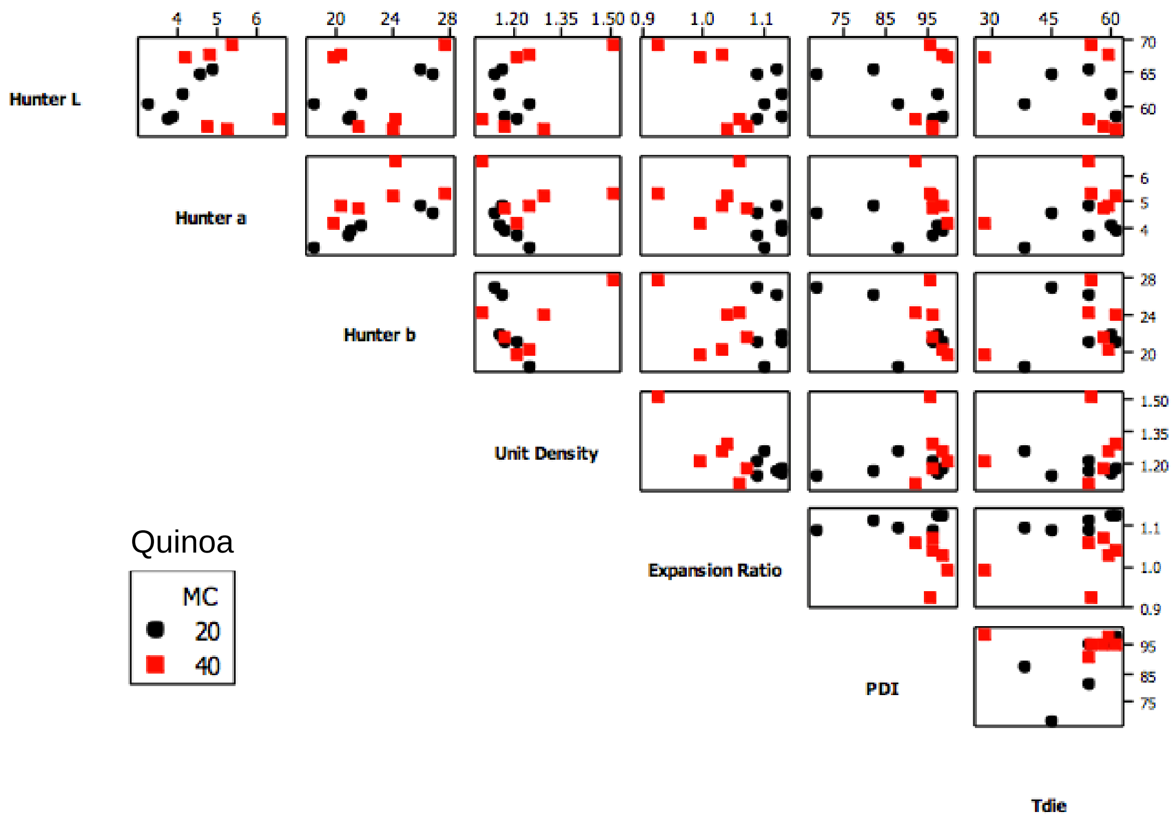

Figure 3: Relationships among all dependent variables. Some clustering was evident due to the different moisture contents.

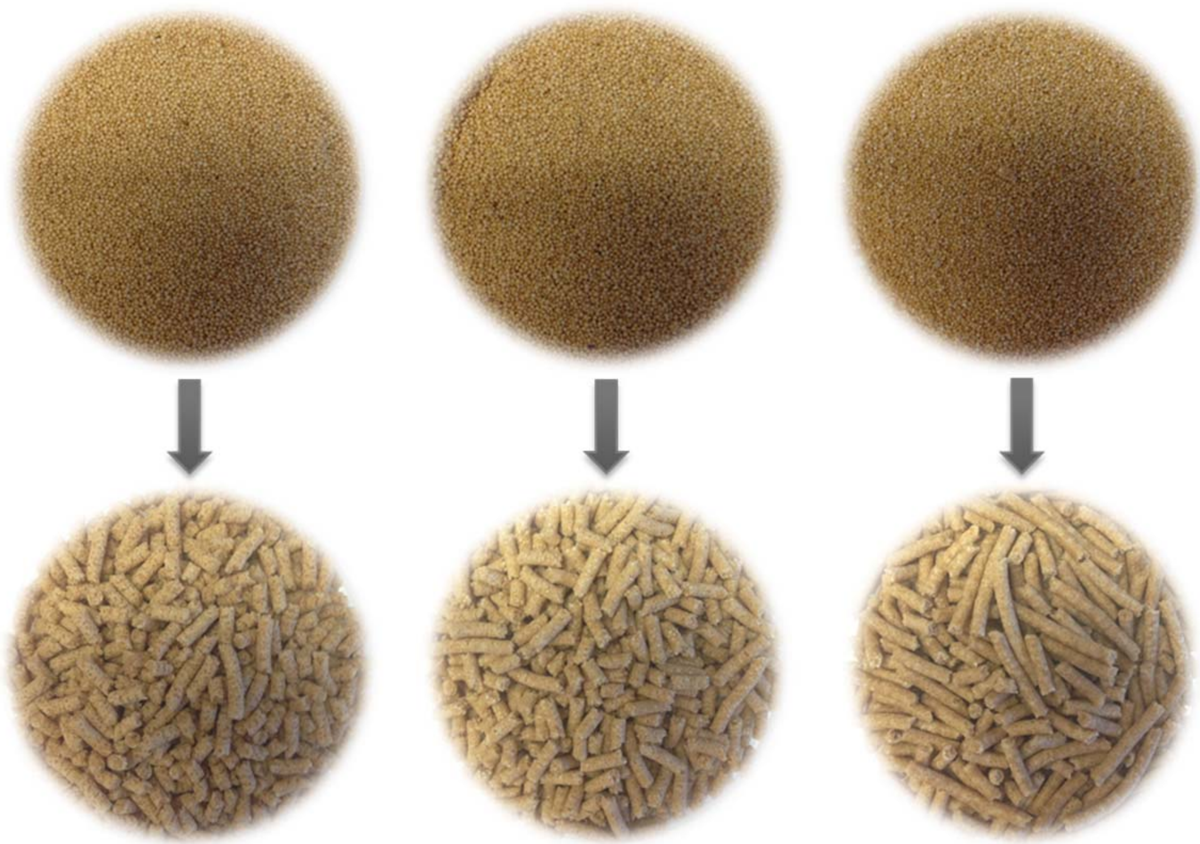

Figure 4: Raw amaranth (above) and extrudates (below) for treatments 2, 6, and 10, respectively.

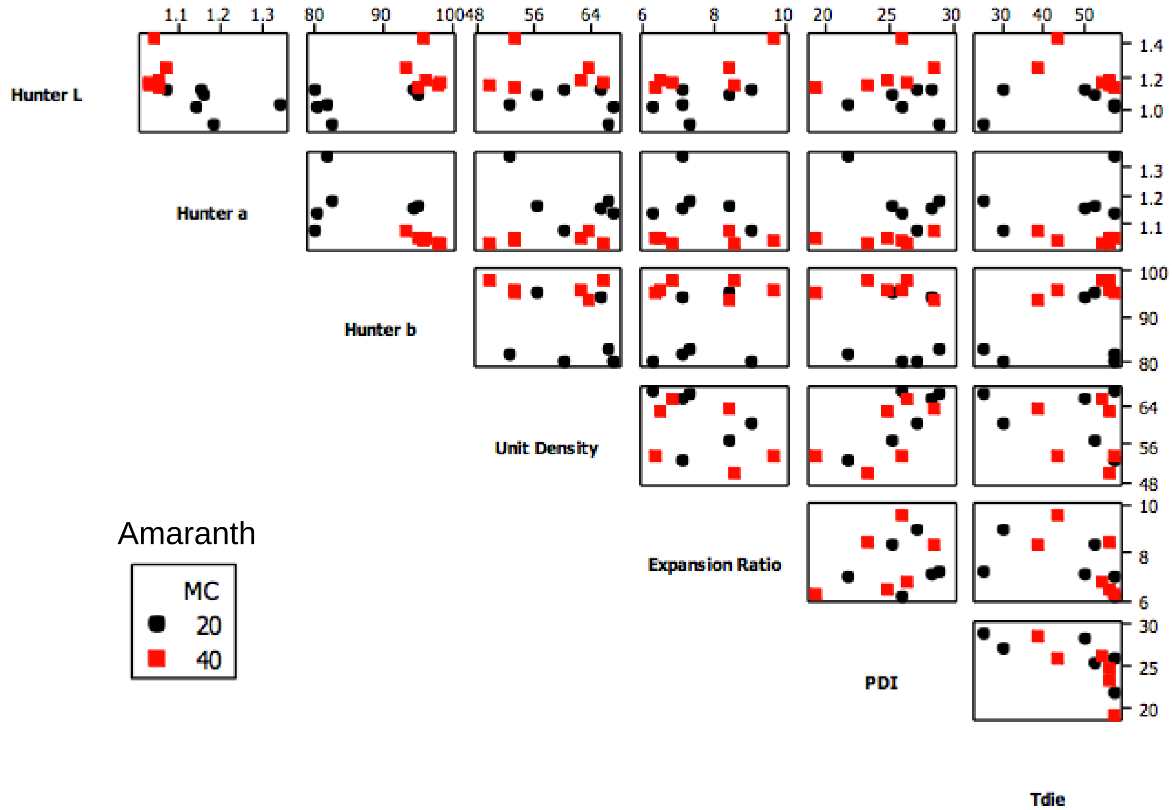

Figure 5: Relationships among all dependent variables. Some clustering was evident due to the different moisture contents.